

# The Effects of Recycled Aggregates on Compressive Strength of Concrete

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**Abstract**— Demolished concrete can be used as recycled concrete aggregate (RCA) for construction purposes. In the research, the compressive strength of concrete made from 100% recycled coarse aggregates and 100% natural coarse aggregates was compared. The values of compressive strength of the natural aggregates concrete (NAC) served as a control. 24 concrete cubes (150 x 150 x 150mm) each for the NAC and RCA were casted making a total of 48 concrete cubes. Three cubes for each category was cured for 3 days, 7 days, 21 days and 28 days respectively. Concrete mix ratios of 1:2:4 and 1:1.5:3 were used in both cases. The results show clearly shown that the compressive strength of RAC was higher than those of NAC at the early ages before day 12. It can be deduced from the graph that the compressive strength of RAC was higher than that of NAC at early ages while the compressive strength of NAC was higher than that of RAC at later ages. This means that RAC will have better usage in quick set concrete where early strength is desired.

**Keywords**— Strength of Concrete, RCA, NAC, C &DW.

## I. INTRODUCTION

Concrete is a mixture of binder materials usually cement, aggregates and water. Aggregate is commonly considered inert filler as they do not get involved in any serious chemical reaction in the process, which accounts for 60 to 80 percent of the volume and 70 to 85 percent of the weight of concrete. Although, aggregate is considered inert fillers, it is a necessary component that defines the concrete's thermal and elastic properties and dimensional stability. Aggregate is classified as two different types, coarse and fine aggregate.

Concrete, one of the dominant construction materials due to its availability, relatively lower cost and the possibility to be cast into desired shapes, has contributed strongly internationally in terms of infrastructure development. The successes are however accompanied by large volumes of construction and demolition waste (C &DW). Recycling of concrete by crushing C &DW and using it as aggregate in structural concrete, has become possible in several countries, where national standards provide for appropriate use of recycled concrete aggregate (RCA).

The use of RCA in construction work started after the Second World War, when many structures were demolished by bombing. During rebuilding, the demolished concrete was used as aggregate in construction. Today, RCA is used successfully in many countries, in many fields such as road construction, protection against erosion, parking areas as well as structural concrete. A number of structures in Germany, Norway, United Kingdom, Finland and Netherlands have been built with RCA as partial or full replacement of natural aggregate.

Coarse aggregate is usually greater than 4.75mm (retained on no. 4 sieve), while fine aggregate is less than 4.75mm (passing the no.4 sieve). The compressive strength is an important factor in the selection of aggregate.

Other physical and mineralogical properties of aggregate must be known before mixing concrete to obtain a desirable mixture. These properties include shape, texture, size gradation, moisture content, specific gravity, reactivity, soundness and bulk unit weight. These properties along with the water/cement ratio determine the strength, workability and durability of concrete.

The shape and texture of aggregate affect the properties of fresh concrete more than hardened concrete. Concrete is more workable when smooth and rounded aggregate is used instead of rough angular or elongated aggregate. Most natural sands and gravel from riverbeds or seashores are smooth and rounded and are excellent aggregate. Crushed stone produces much more angular and elongated aggregates, which have a higher surface-to-volume ratio, better bond characteristics but requires more cement paste to produce a workable mixture. A smooth surface can improve workability, yet a rougher surface generates a stronger bond between the paste and the aggregate creating a higher strength.

The advantages of using recycled concrete product as road base aggregates includes:

- Recycled concrete is non-expansive and will not grow or expand with moisture.
- Recycled concrete has optimum moisture of approximately 13 percent about twice that of natural road base, due to its particles size

distribution, it may absorb twice the water before becoming saturated.

- Recycled concrete is 10-15 percent lighter in weight, resulting in reduced transportation cost.
- Recycled concrete compact faster-up to two to three times as fast as non-stabilized natural road base.

## II. LITERATURE REVIEW

The particle shape analysis of recycled aggregate indicates similar particle shape of natural aggregate obtained from crushed rock.

The recycled aggregates which originated from a low strength concrete had less adhered mortar and the high strength concrete had more adhered mortar, when the crushed concrete was grinded with the same type of the machine and the same energy applied. Prasad et al. (2007) noted that the specific gravity of demolished concrete aggregates is lower than that of natural aggregate. The average specific gravity of aggregate usually varies from 2.6 to 2.8. Bairagi et al. (1993) concluded that very rapid rates of absorption are observed for recycle aggregate. Nearly 75% of the 24hour absorption capacity was attained in the first 30 minutes of the soaking period. In accordance with Hansen et al. (1983), recycled aggregate concrete made with recycled coarse aggregates and natural sand needs 5% more water than conventional concrete in order to obtain the same workability. If the sand was also recycled, 15% more amount of water was necessary to obtain the same workability. Tavakoli et al. (1996) demonstrated that concrete made with 100% recycled aggregate with lower W/C ratio than the conventional concrete can have a larger compressive strength. When the W/C ratio is the same, the compressive strength of concrete made with 100% recycled aggregate was lower.

Though researchers have reported a reduction in strength in recycled aggregate, it should be noted that the extent of reduction is related to the parameters such as the type of concrete used for making the recycle aggregate (high, medium or low strength), replacement ratio, water/cement ratio and the moisture condition of the recycled aggregate (Cretnsil et al., 2001). At a high w/c ratio (between 0.6 and 0.75), the strength of recycled aggregate is comparable to that of reference concrete even at a replacement level of 75% (Katz, 2003). Hansen et al. (1983) concluded that, not only the w/c ratio influences the compressive strength of concrete made with 100% of recycled aggregate, but the compressive strength of the recycled aggregate concrete also depends on the strength of the original concrete. The compressive strength of recycled aggregate concrete is strongly controlled by the combination of w/c ratio of the original concrete, when

other factors are essentially equal. Therefore, dependence exists with respect to the old w/c ratio. Bairagi et al. (1993) concluded that the average relative compressive strength varies from 98 to 94% when the replacement ratio is varied from 0.25 to 0.50. For the replacement ratio 1.0 the average relative compressive strength was 86%.

Salem et al. (1998) concluded that the compressive strength of concrete made with 100% of recycled aggregate increases by 2% from 7 to 28 days with respect to the 16% increase by conventional concrete. This could be due to either the absorption capacity of the recycled aggregate or the bad adherence of the aggregate with the Cementpaste. In particular, the strength of the concrete with HPC recycled aggregates reached the level of the concrete prepared with the crushed natural granite aggregates after 90 days of curing. The difference in the strength development between the concretes with high-performance concrete and normal-strength concrete recycled aggregates was due to the differences in both the strength of the coarse aggregates and the microstructural properties of the interfacial transition zones.

## III. MATERIALS AND METHOD

Laboratory tests was carried out to obtain the relevant data and information needed to aid this project such as sieve analysis determination, specific gravity determination, bulk density determination and compressive strength test.

### 3.1 Sourcing of Aggregate

The recycled aggregate for this project was sourced from demolished culverts concrete and crushed concrete cubes from CRUTECH laboratory in Calabar. The recycled aggregate was afterwards manually crushed in the laboratory, filtered and graded in accordance with British Standards (812, 1974, 1990).

The natural coarse aggregate and fine aggregates was sourced from heaps of commercial supply of crushed quarried natural aggregates within Calabar.

### 3.2 Experimental Work

The experimental works were directed towards achieving the aim of this research. Comparison of two grades of concrete using basic properties of recycled aggregate and natural aggregate was made. The compressive strength was the main criteria used in the comparison. Two concrete types were tested within the research project. Mix proportions of the concrete types were tested in accordance with the following conditions:

- Same cement content
- Same workability
- Same maximum grain size (25mm)
- Same grain size distribution of aggregate mixture
- Same type and quantity of fine aggregate.

The type and quantity of coarse aggregate varied in the following ways:

- The first concrete mix had 100% natural coarse aggregate (NCA).
- The second concrete mix had 100% recycled coarse aggregate.

### 3.3 Casting Of Concrete Samples

Casting was done for concrete cubes to test for the compressive strength. The mould used for the research work was a steel mould of size 150x150x150mm, it was oiled to avoid friction during moulding and de-moulding of concrete cubes. Mix ratios of 1:2:4 and 1:1.5:3 were used.

Table.3.1: Schedule of Samples Per mix Ratio

	3 Days	7 Days	14 Days	21 Days	28 Days
Number of cubes (150x150x150mm)	RAC 3	3	3	3	3
	NAC 3	3	3	3	3

## IV. RESULTS AND ANALYSIS

The data used for this project were results obtained from laboratory test conducted on Natural Aggregate Concrete (NAC) and Recycled Aggregate Concrete (RAC) specimens at the Material Testing Laboratory, Cross River University of Technology, CRUTECH, Calabar.

Table.4.1: Compressive Strength Test Result on Natural Aggregate Concrete NAC, Mix Ratio 1:2:4

Age of Cubes (Days)	Compressive strength in N/mm <sup>2</sup>
3	11.5
7	14.0
14	17.6
21	19.7
28	21.1

Figure 4.1 below shows the average compressive strength of natural aggregate concrete (NAC) versus age. As the age increases, the compressive strength also increased.

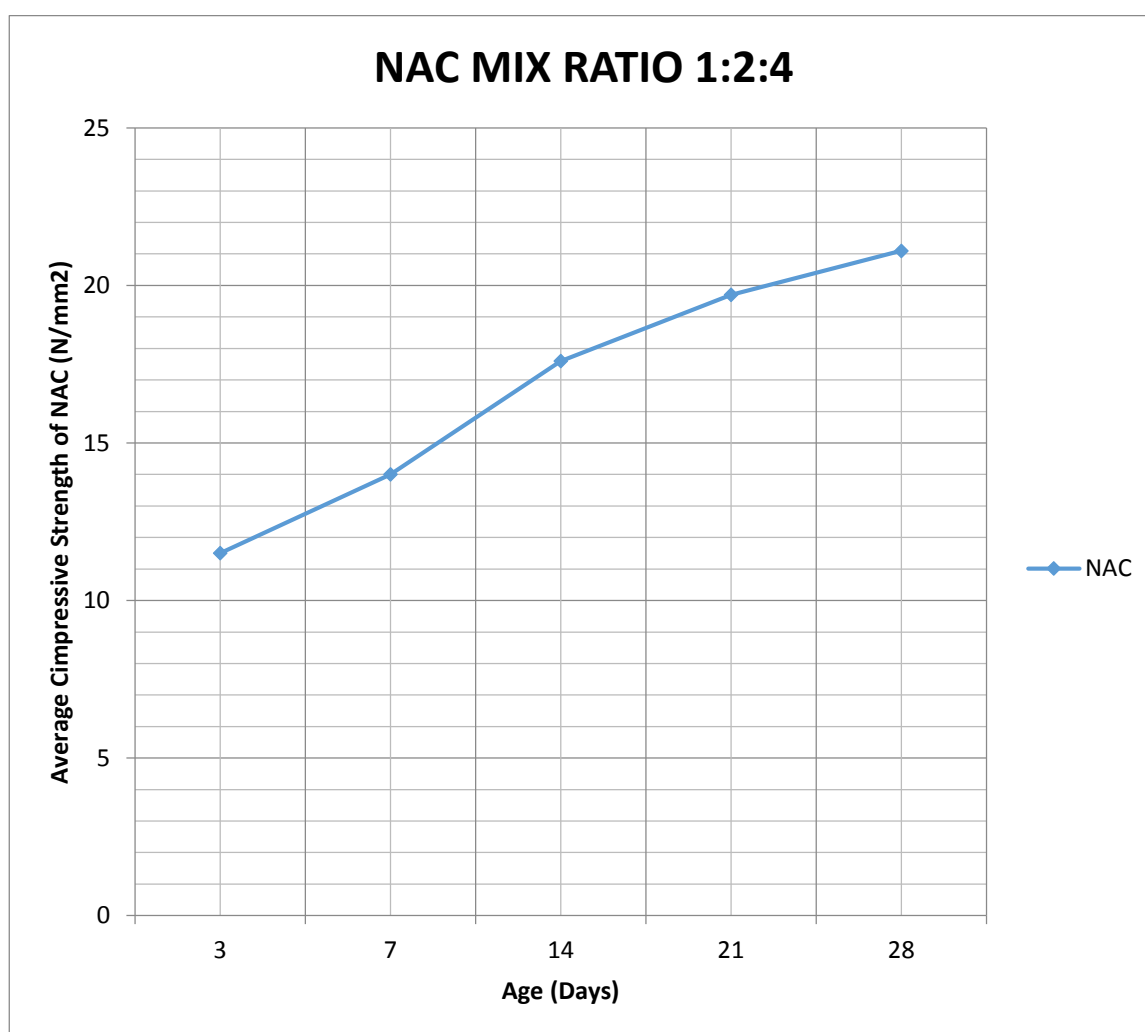


Fig.4.1: Graph of compressive strength versus age for NAC with mix ratio 1:2:4

Table.4.2: Compressive Strength Test Results Of Recycled Aggregate Concrete RAC for Mix Ratio 1:2:4

Age of Cubes (Days)	Compressive strength in N/mm <sup>2</sup>
3	13.0
7	15.3
14	17.2
21	18.9
28	20.5

Figure 4.2 shows the average compressive strength of recycled aggregate concrete (RAC) versus age for mix ratio 1:2:4. As the age increases, the average compressive strength increased.

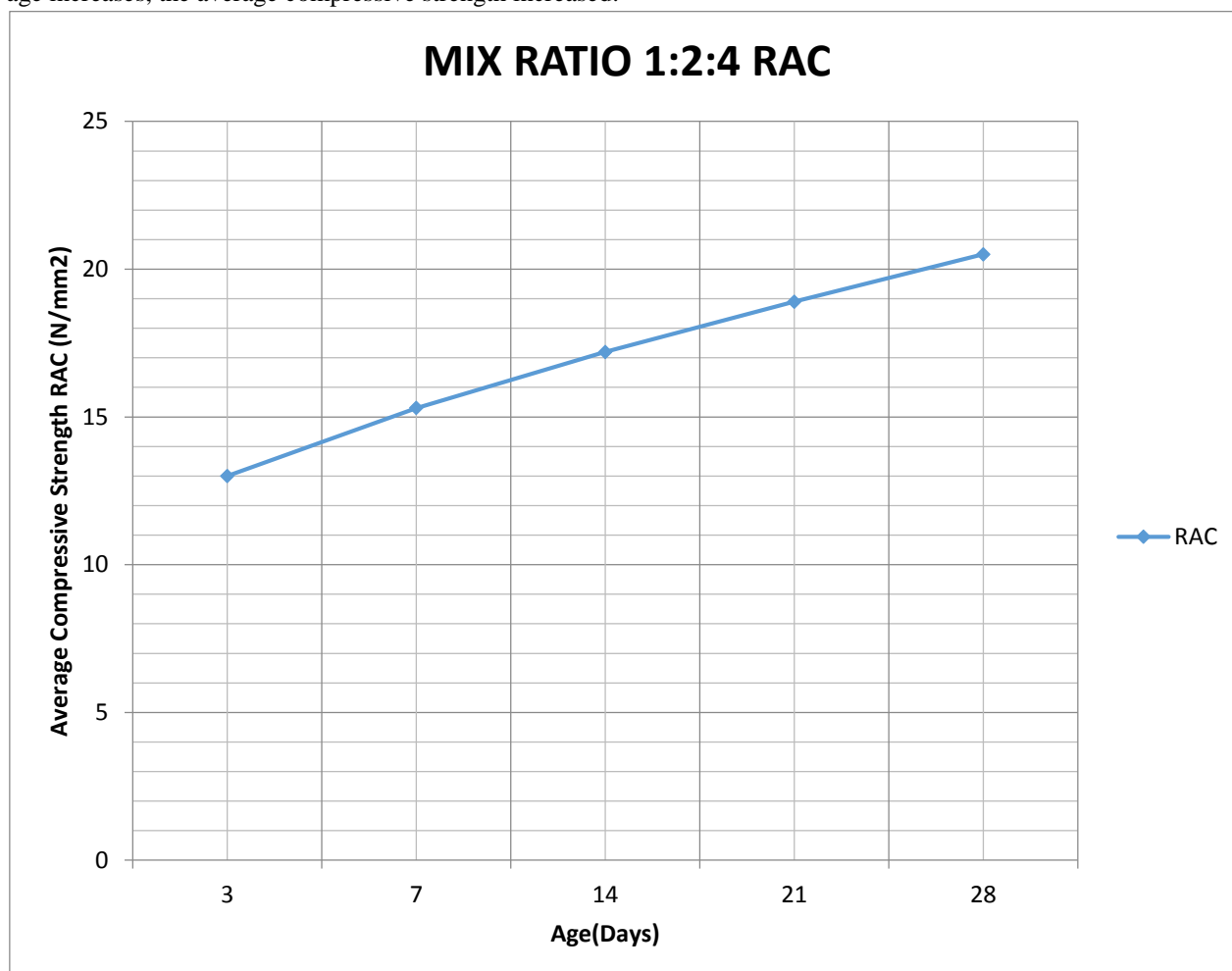


Fig.4.2: Graph of compressive strength versus age for RAC with mix ratio 1:2:4

Table.4.3: Comparison Of NAC And RAC With Mix Ratio 1:2:4

Age of Cubes (Days)	Compressive strength in N/mm <sup>2</sup> for NAC	Compressive strength in N/mm <sup>2</sup> for RAC
3	11.5	13.0
7	14.0	15.3
14	17.6	17.2
21	19.7	18.9
28	21.1	20.5

Figure 4.3 shows the comparison for mix ratio 1:2:4 for NAC and RAC. In the graph, it is clearly shown that the compressive strength of RAC was higher than those of NAC at the early ages before day 12. At age of 12 days, there was an intersection point between RAC and NAC and there was an equal and average compressive strength of about 16.8 N/mm<sup>2</sup>. After this age of 12 days, it was observed that the average compressive strength of NAC started rising above that of RAC. It can be deduced from the graph that the compressive strength of RAC was higher than that of NAC at early ages while the compressive strength of NAC was higher than that of RAC at later ages. This means that RAC will have better usage in quick set concrete where early strength is desired.

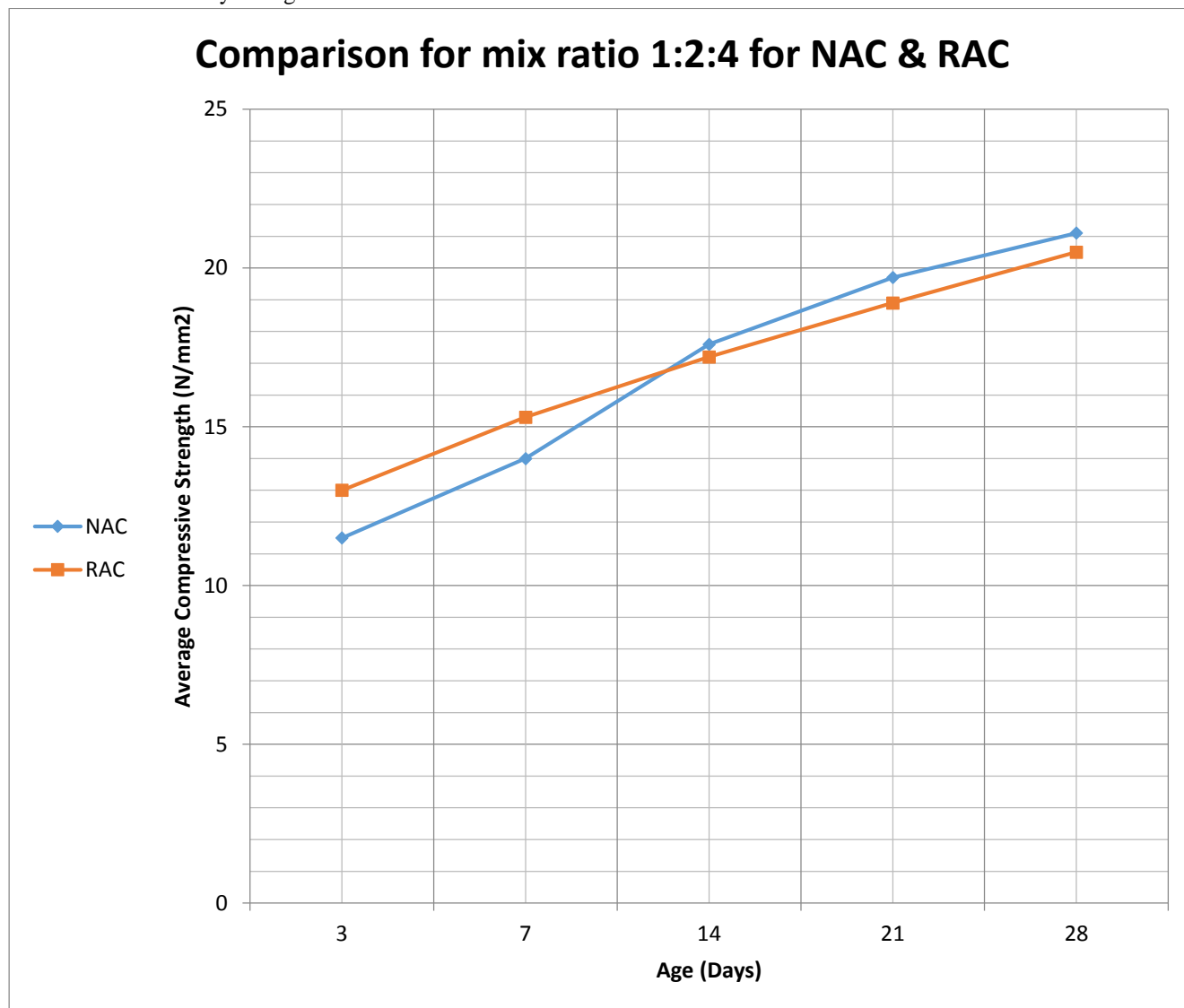


Fig.4.3: Graph of compressive strength versus age for RAC and NAC versus age for mix ratio 1:2:4

Table.4.4: Compressive Strength Test Results of NAC With Mix Ratio 1:1.5:3

Age of Cubes (Days)	Natural Aggregate Concrete (NAC)
3	14.8
7	18.3
14	20.5
21	24.9
28	29.8

Figure 4.4 below shows the average compressive strength of natural aggregate concrete (NAC) versus age for mix ratio 1:1.5:3. As the age increases, the average compressive strength increased.

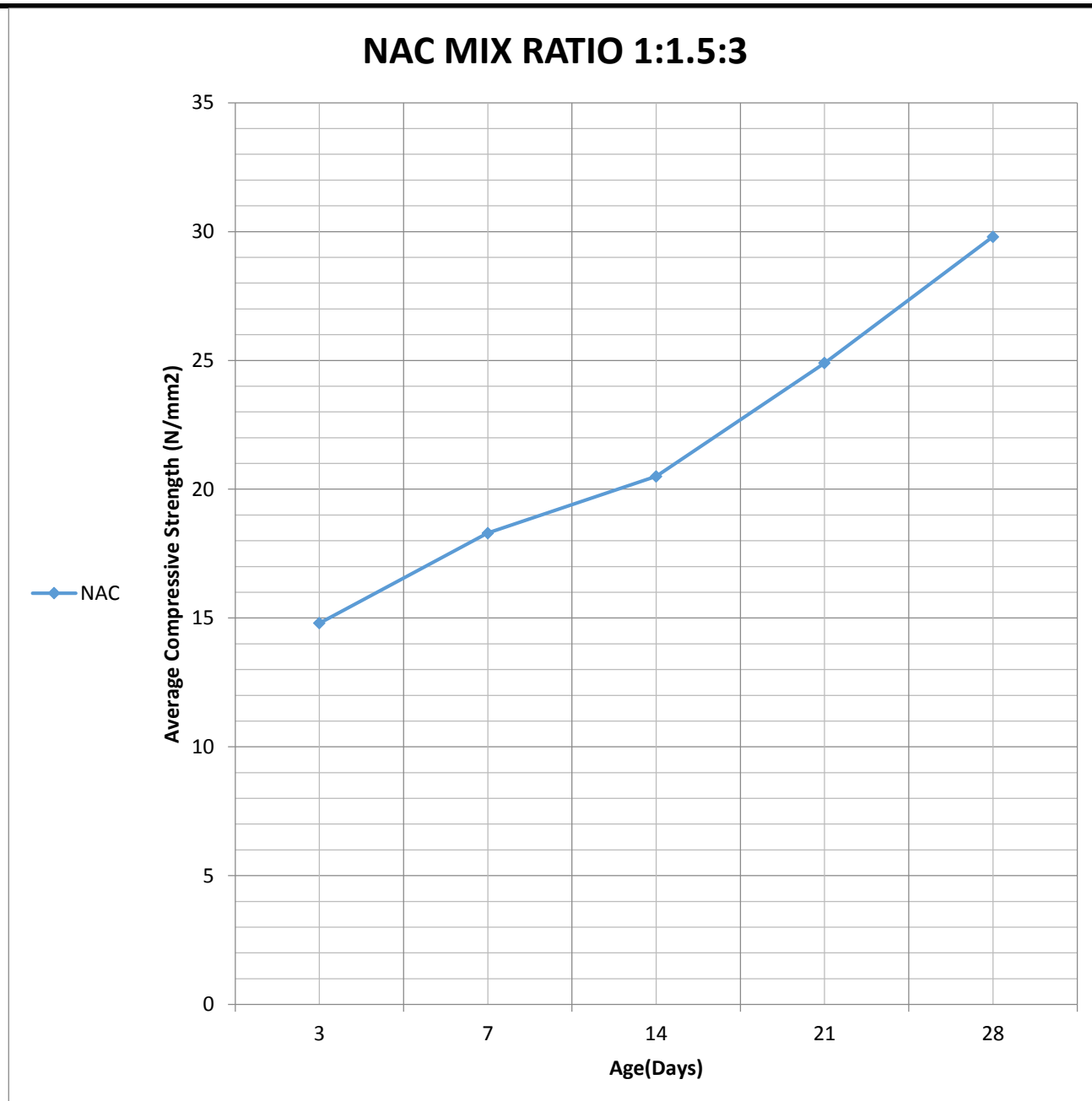


Fig.4.4: Graph of Average Compressive Strength versus Age (Days) for NAC with mix ratio 1:1.5:3

Table.4.5: Compressive Strength Test Result Of RAC With Mix Ratio 1:1.5:3

Age of Cubes (Days)	Recycled Aggregate Concrete (RAC)
3	14.5
7	19.5
14	21.0
21	24.5
28	30.2

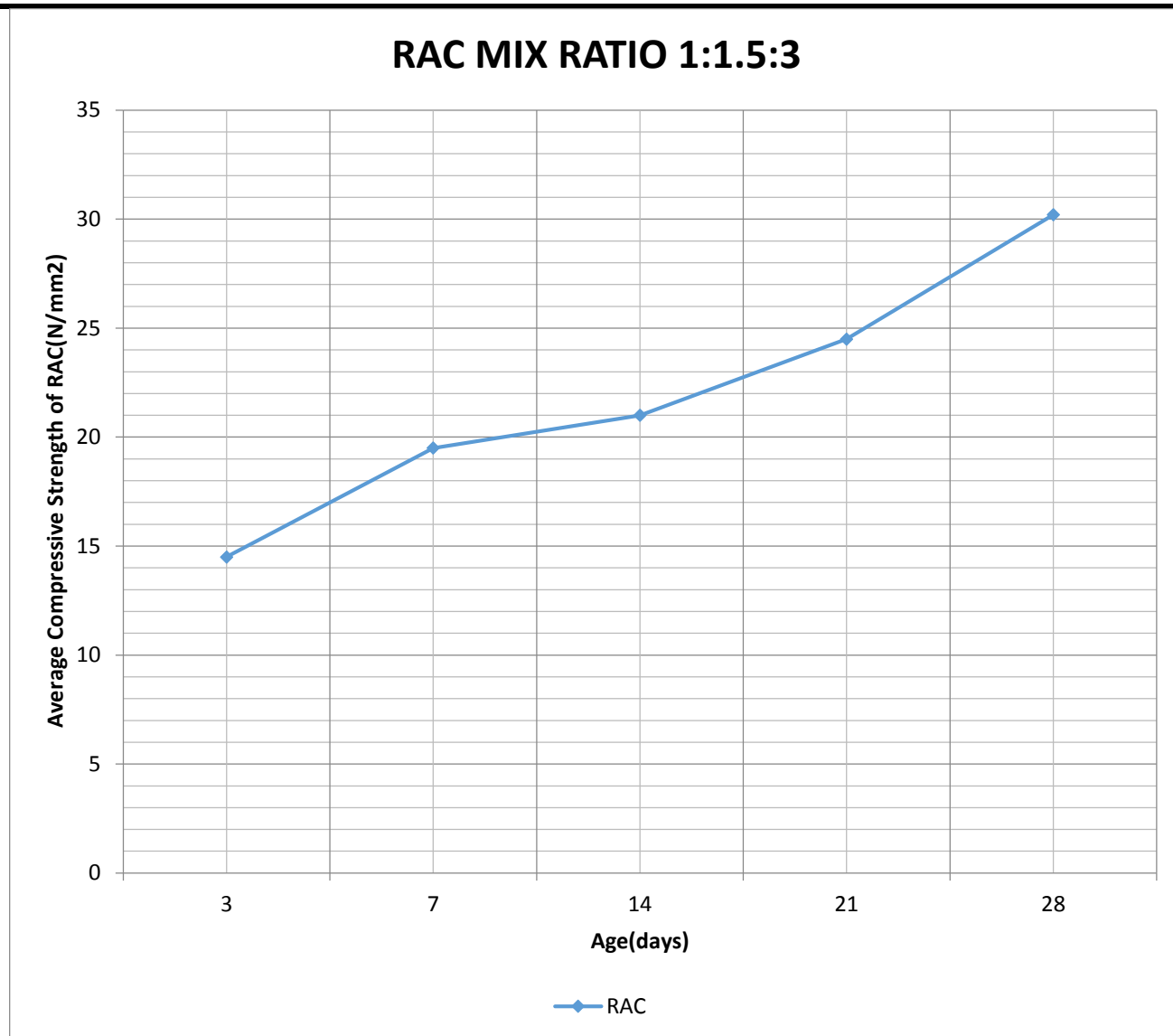


Fig.4.5: Average Compressive Strength versus Age (Days) for Recycled Aggregate Concrete (RAC) for mix ratio 1:1.5:3

Table.4.7: Comparison Of Compressive Strength Test Result For RAC and NAC, Mix Ratio 1:1.5:3

Age of Cubes (Days)	Natural Aggregate Concrete (NAC)	Recycled Aggregate Concrete (RAC)
3	14.8	14.5
7	18.3	19.5
14	20.5	21.0
21	24.9	24.5
28	29.8	30.2

At the early stage, compressive strength for RAC was higher than NAC. In figure 4.6, at age of 12 days, there was an intersection between RAC and NAC at an average compressive strength of about  $16.8\text{N/mm}^2$  and at that point. It can be deduced from the graph that the compressive strength of RAC was higher than that of NAC at early ages while the compressive strength of NAC was higher than that of RAC at later ages. This means that RAC will have better usage in quick set concrete where early strength is desired.

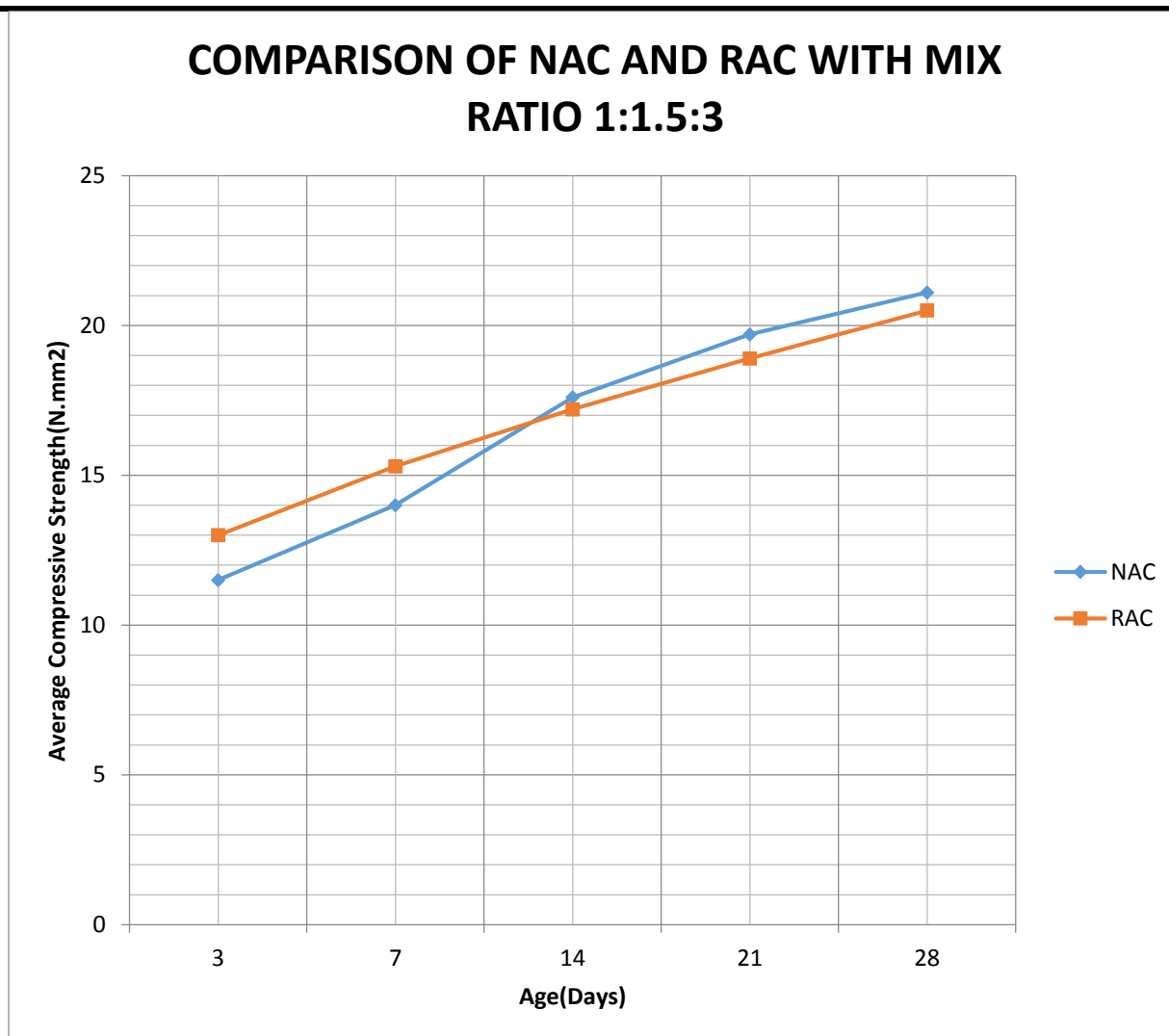


Fig.4.6: Comparison Of Average Compressive Strength versus Age (Days) for RAC and NAC with mix ratio 1:1.5:3

## V. CONCLUSION AND RECOMMENDATION

### 5.1 Conclusion

The following conclusions can be drawn from the results of experimental study to compare the compressive strength of concrete made with recycled aggregate and natural aggregate:

With constant water cement ratio and mix design, the early compressive strength of RCA concrete is higher than that of NCA concrete. However, at later ages, the compressive strength of NCA concretes were slightly greater than those of RCA by a little margin of about 10%. It was observed that the performance of concrete with RCA was slightly lower than NCA.

It was also observed that the concrete manufactured with RCA provided less compressive strength as compared to NCA. However, this reduction is considerably small, as such; RCA can be used comfortably in concrete structures with modifications to meet specific and desired purpose.

### 5.2 Recommendation

The following recommendations can be made from the research:

- Concretes made with RCA have equivalent compressive strength with those made from NCA provided the mix ratio and water cement ratio are not varied.
- Concretes made from RCA have higher early compressive strength compared to those made from NCA
- The use of RCA in concrete should be encouraged by legislation to solve environmental problems of disposal and depletion of natural aggregates.
- The process of preparation of recycled aggregate plays a significant role in determination of the strength of the recycled aggregate concrete. If not properly crushed and washed to remove the adhered mortar, the concrete density will be low thus reduction in strength.

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